

How Big Were Original Planetesimals?

S. J. Weidenschilling

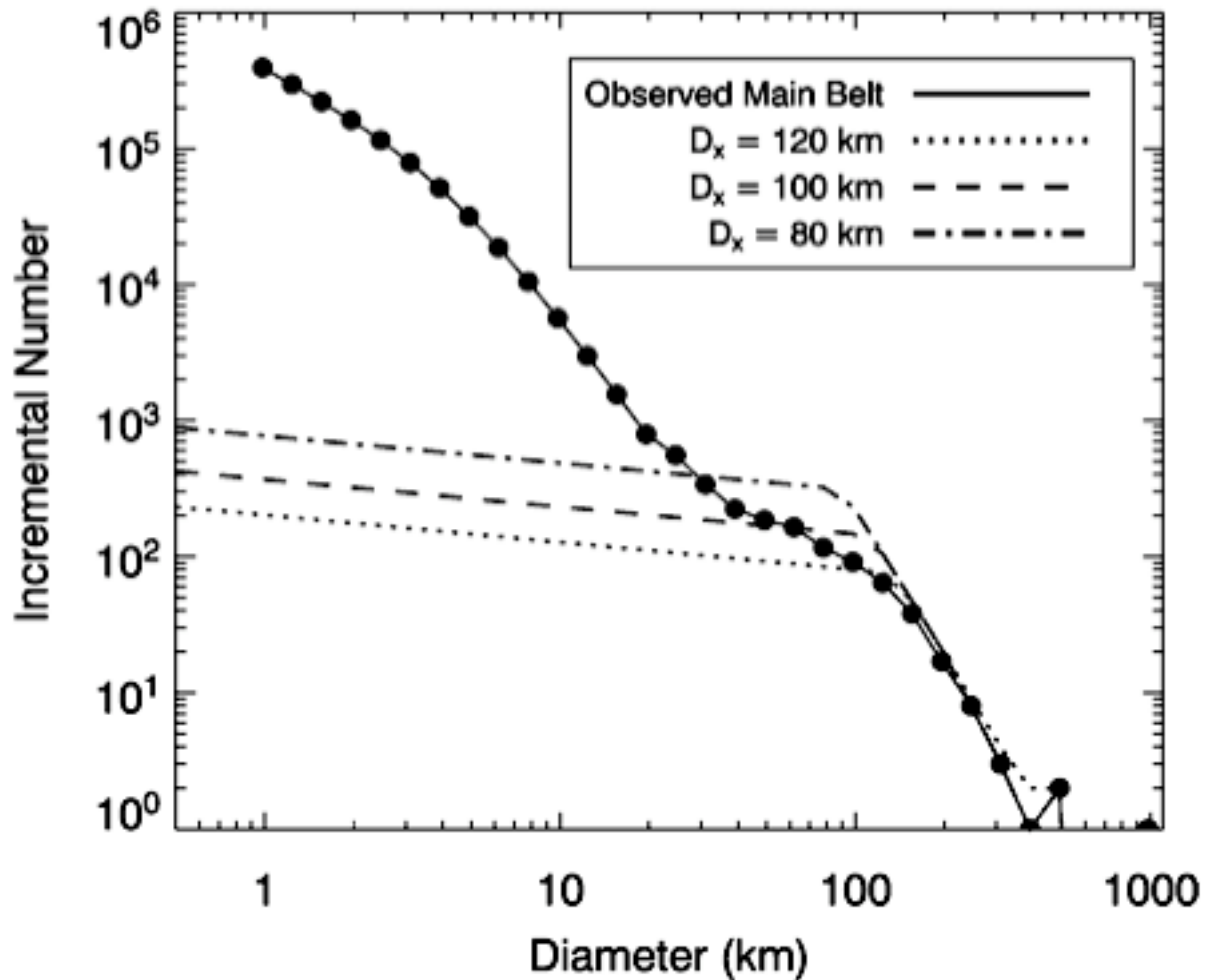
Disk Workshop

JPL/Caltech, March 2008

History of the Asteroid Belt (Abridged)

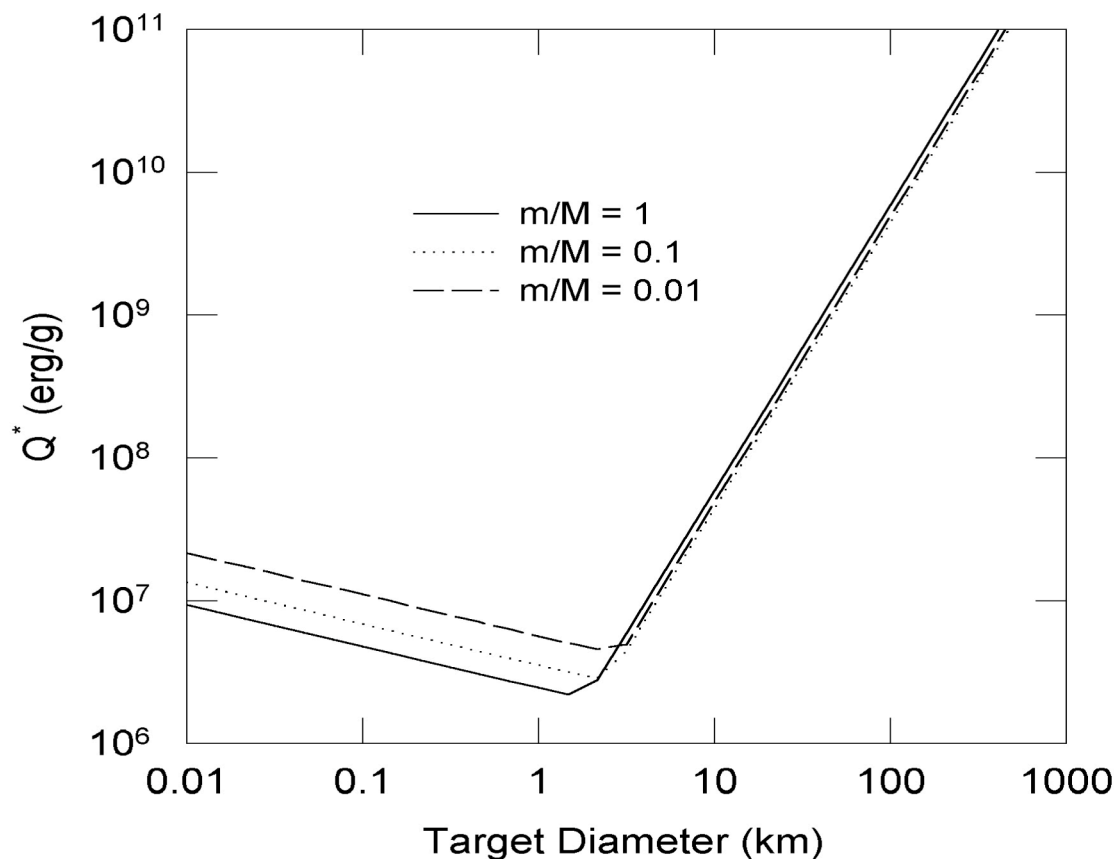
- Primordial planetesimals formed
- Planetary embryos accreted
- Excitation of velocities, dynamical depletion after Jupiter's formation
- 4.5 Gy of collisional evolution
- Does the present population depend on the primordial distribution?

Initial size Distribution Evolves to Present-day Asteroid Belt (not a power law) (Bottke et al. 2005)



- Bottke et al.: “initial” population that evolves to the present belt was dominated by ~ 100 km bodies
- This population did not represent the production function of planetesimals, but the bodies present after the belt was stirred and depleted of large embryos
- Can 100 km “bump” be produced by accretion of smaller primordial planetesimals?

Impact Strength $Q^* = \text{energy/mass yielding } 1/2$
of target mass (monolithic or rubble pile)



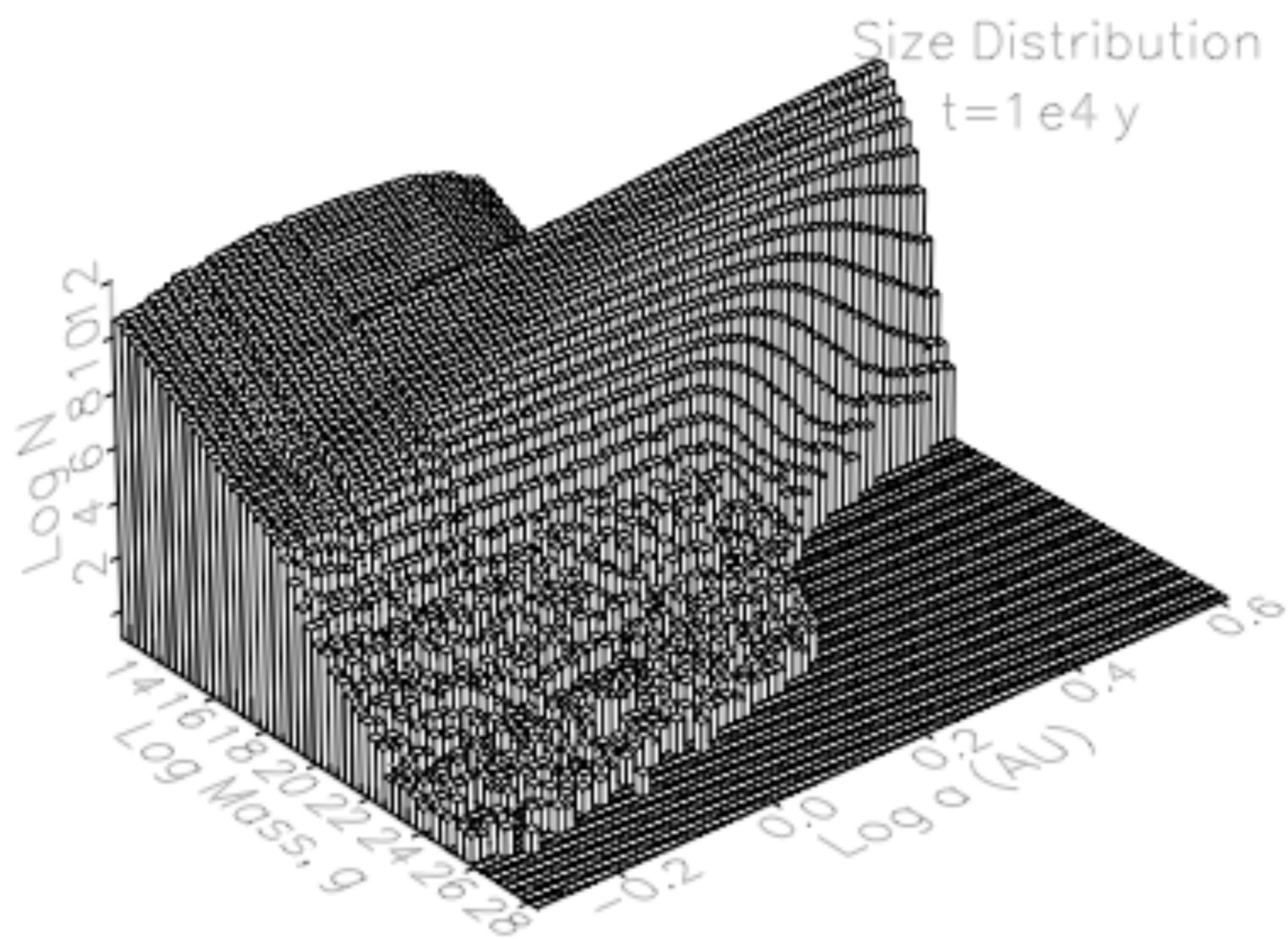
$D < 1$ km: material strength dominates, decreases with size due to presence of flaws

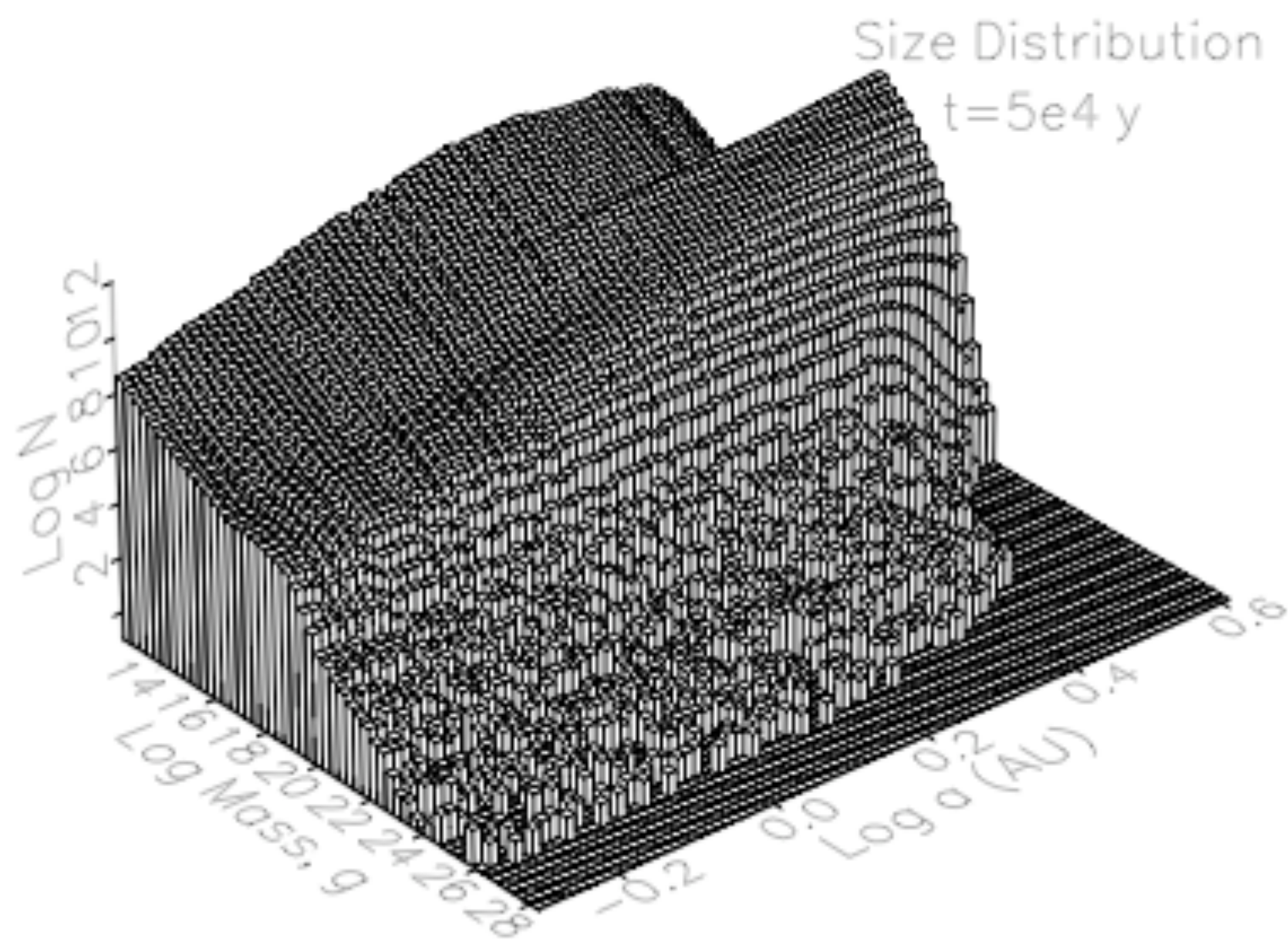
$D > 1$ km: gravitational binding energy increases with size

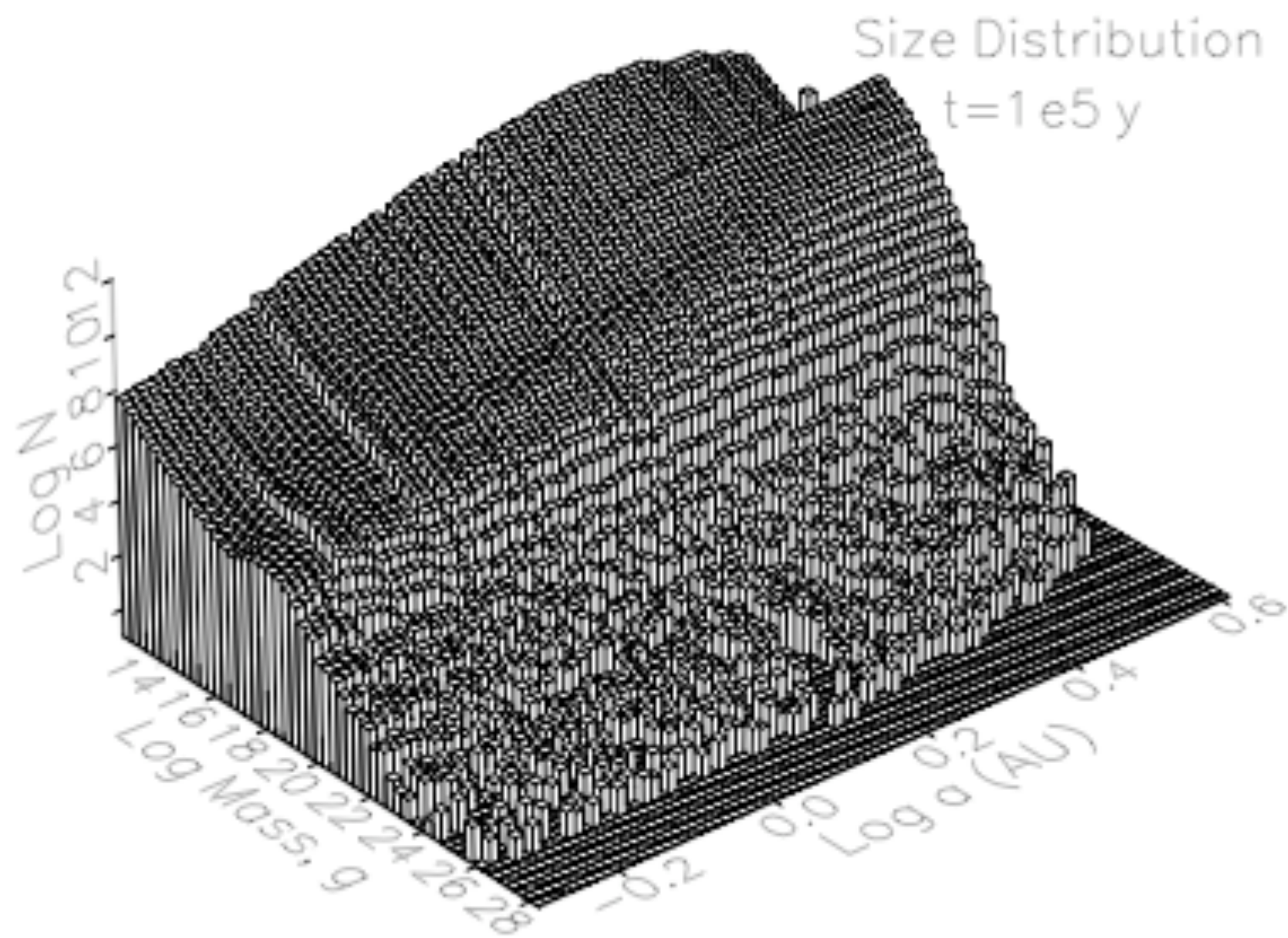
Minimum strength at $D \sim 1$ km

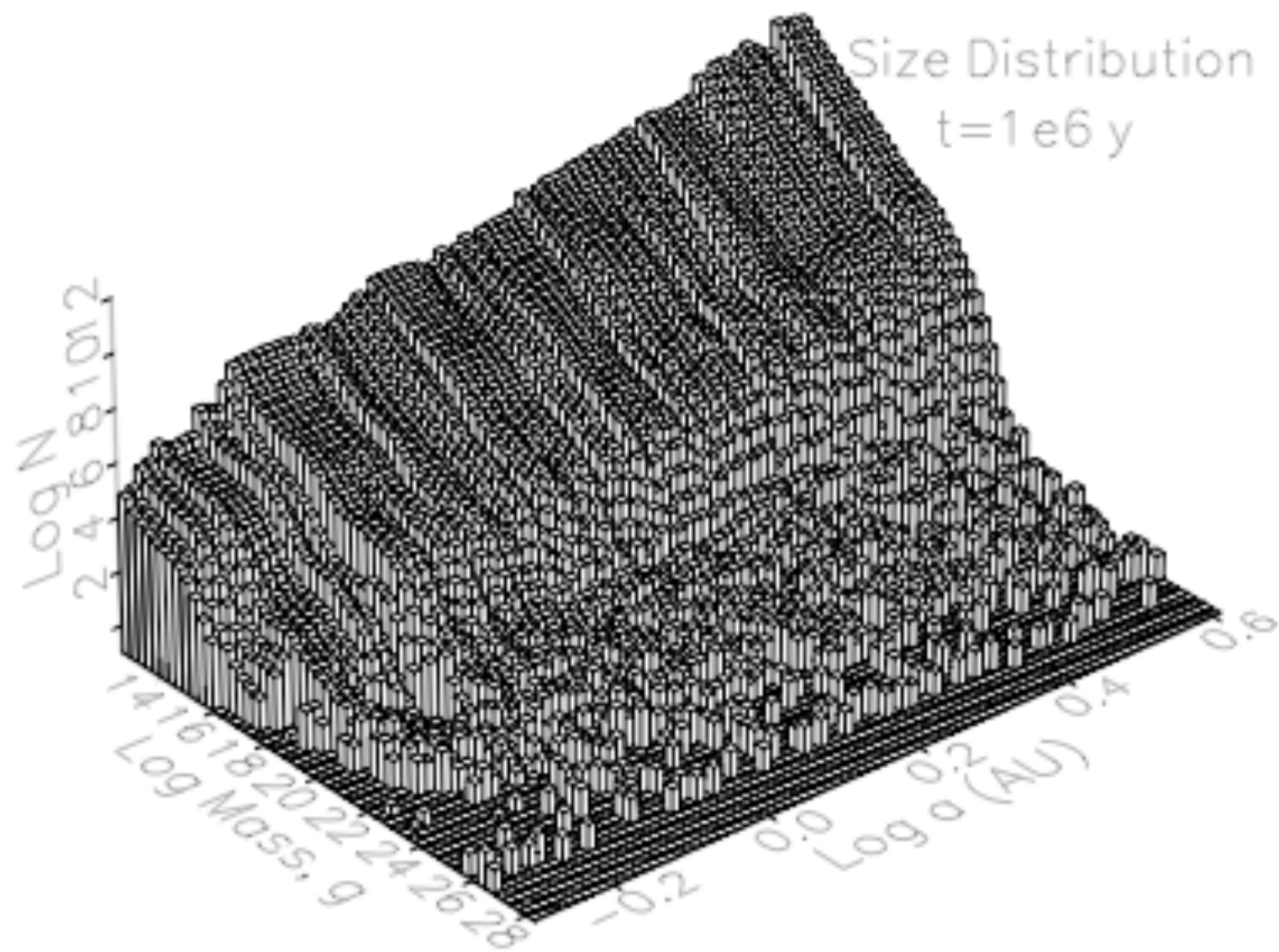
Modeling Accretional Evolution

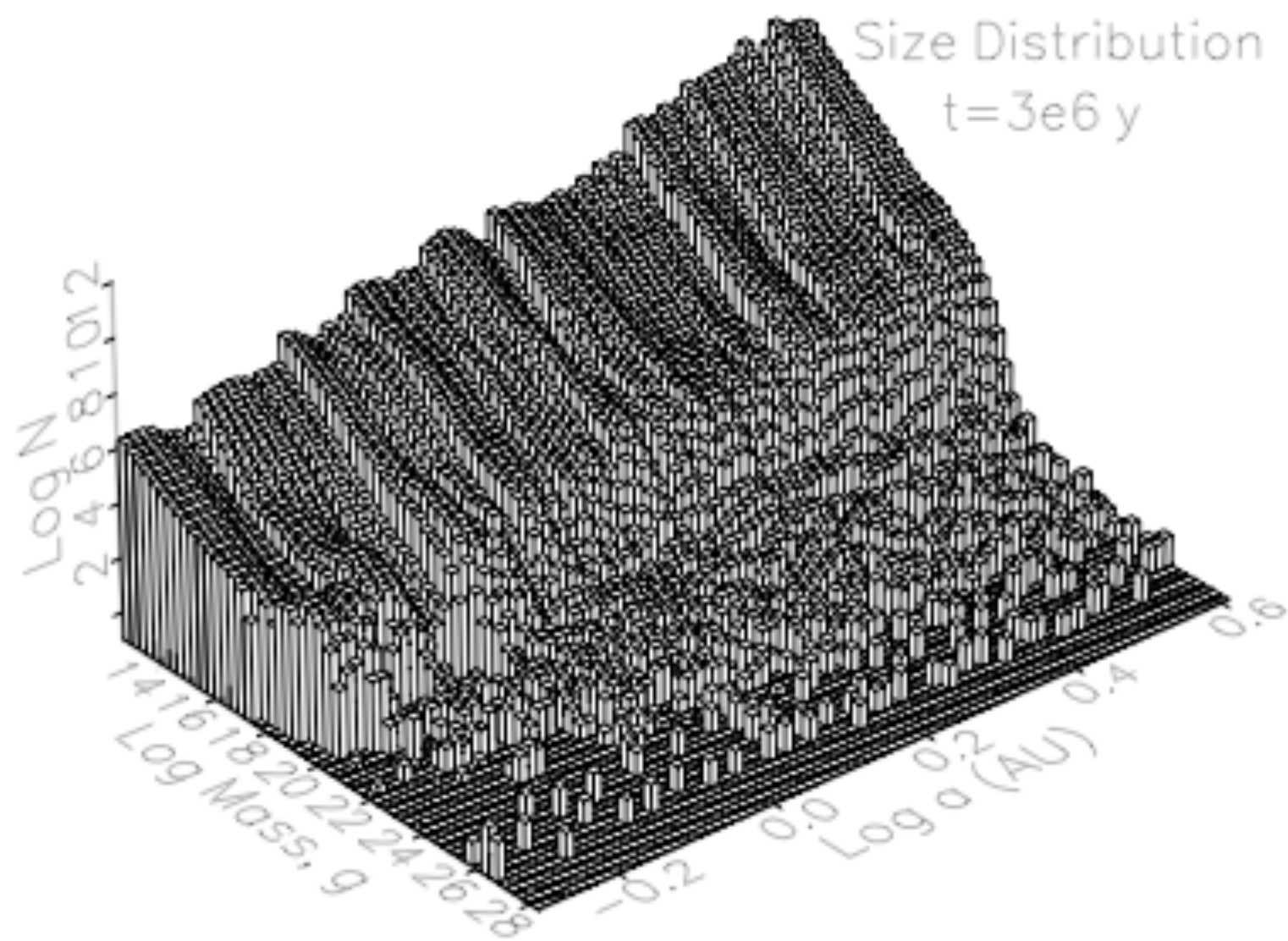
- Initial planetesimal diameter (arbitrary, single size)
- Accretion and fragmentation; fragments smaller than $1/8$ km are lost
- Gravitational stirring by embryos
- Aerodynamic drag acts on small bodies
- Large bodies interact tidally with gas, causing decay of semimajor axes (Type 1 migration), and damping of eccentricities and inclinations
- Gas decays exponentially on timescale 2 My

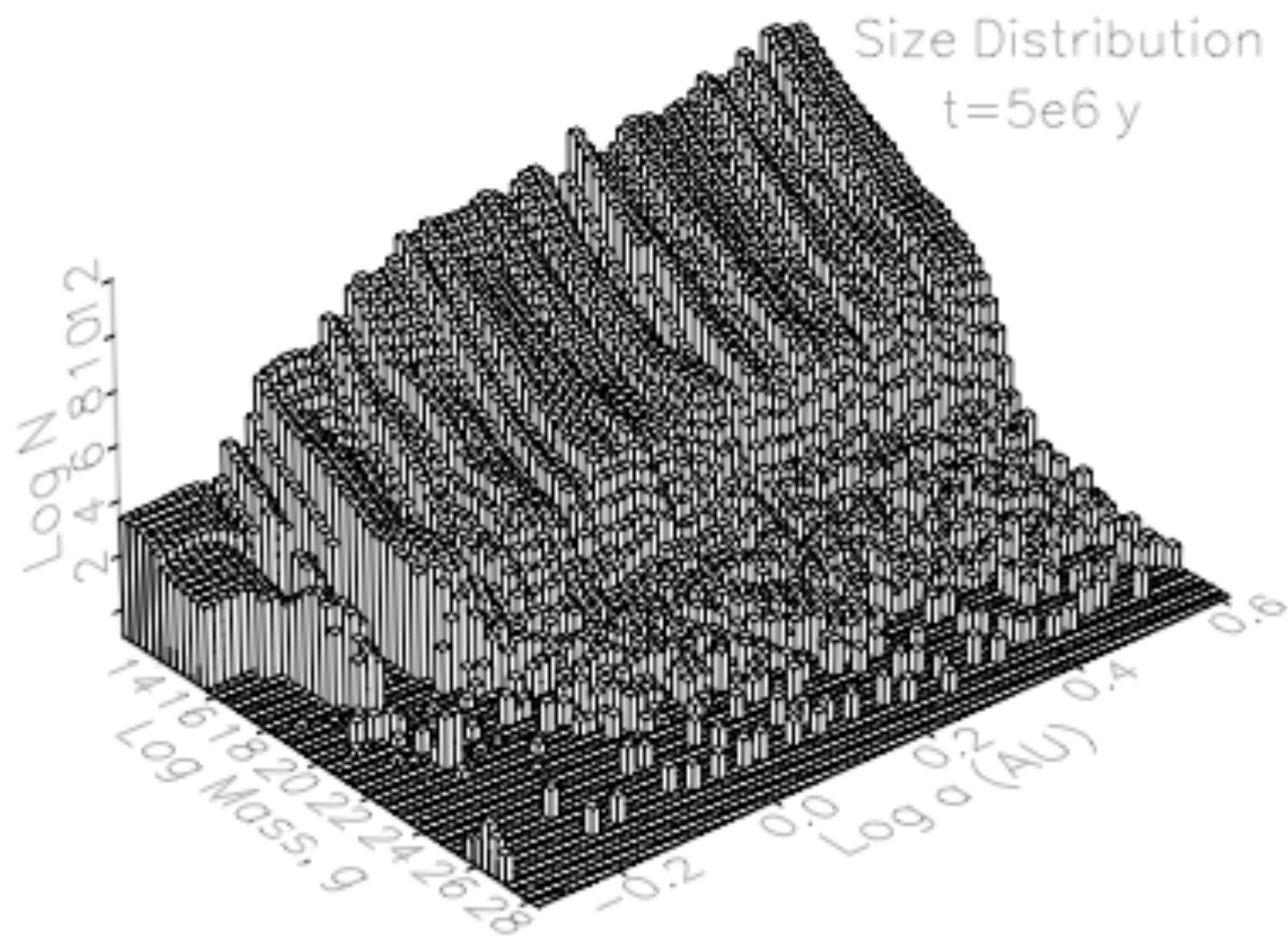




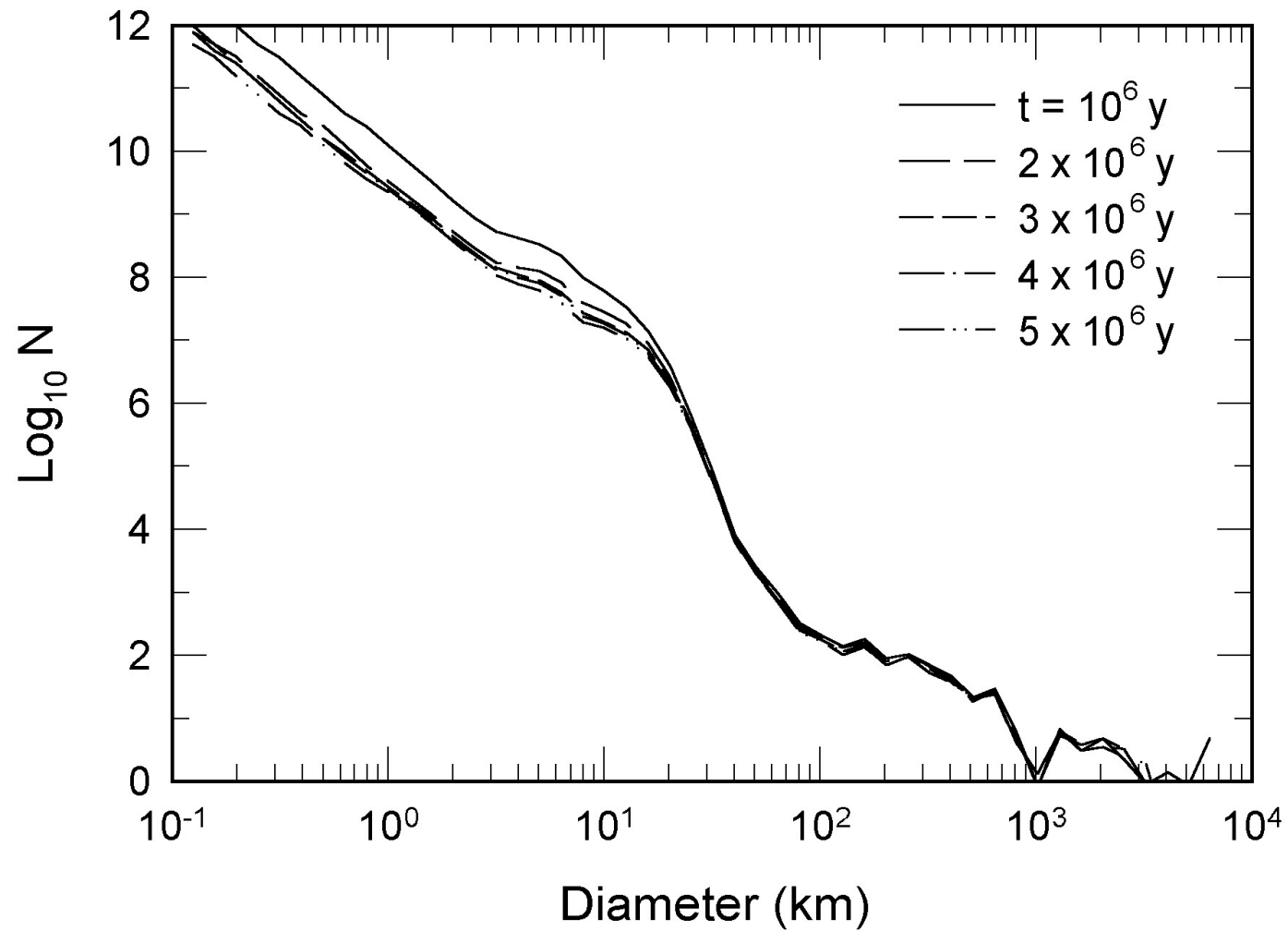




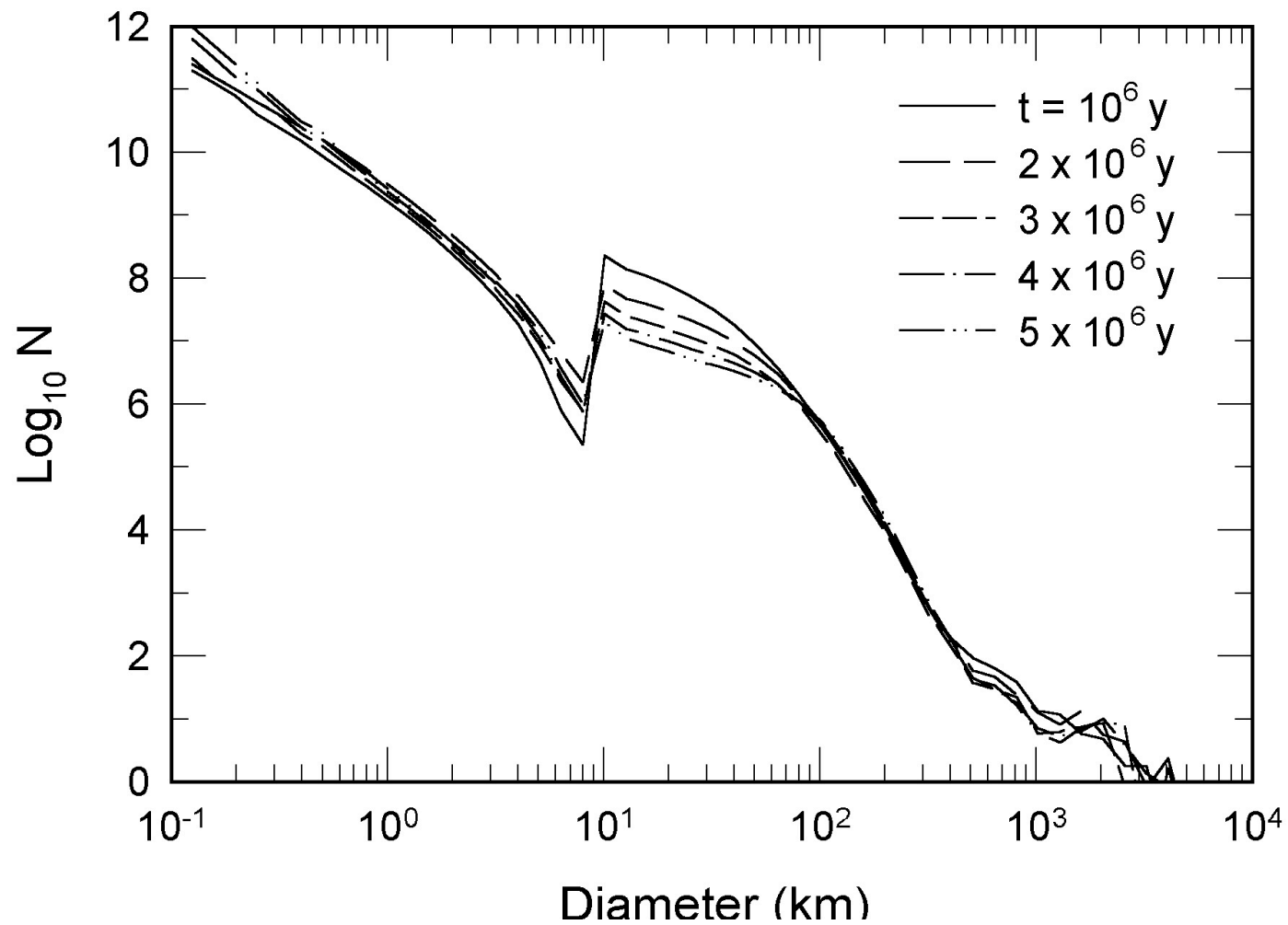




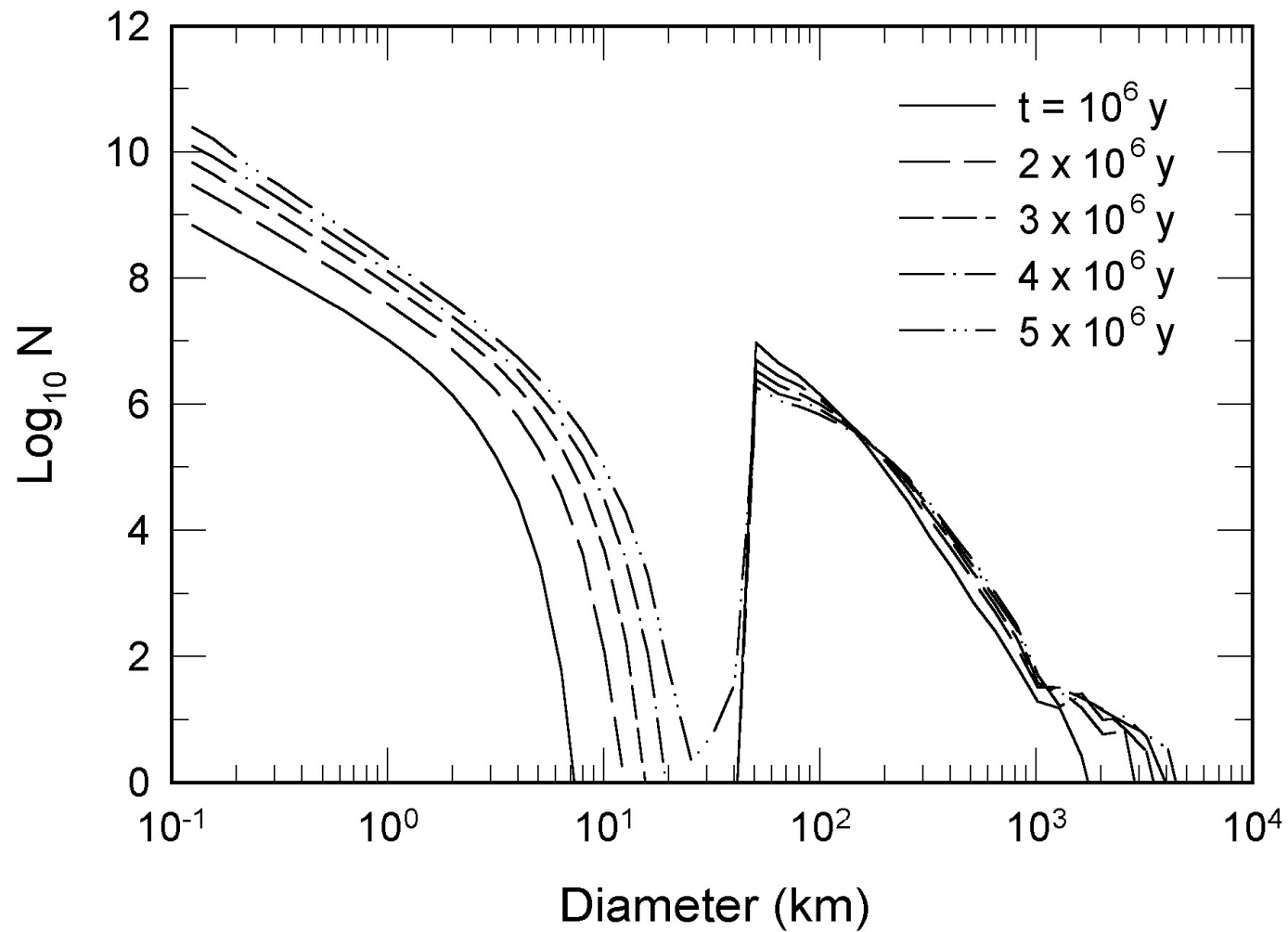
Initial Diameter 1 km 2 - 3.25 AU



Initial Diameter 10 km 2 - 3.25 AU



Initial Diameter 50 km 2 - 3.25 AU



Conclusions

- The “initial” asteroidal size distribution cannot be produced by accretion (with fragmentation and runaway growth) from km-sized “primordial” planetesimals
- The initial size had to be larger; in the range ~ 10 - 50 km diameter
- If too large, > 100 km (monodisperse), not enough smaller asteroids are produced by later collisional evolution

Why Does Size Matter?

- Runaway accretion tends to produce a bimodal population of small bodies near the starting size and large embryos
- The timescale for onset of runaway growth is proportional to initial size
- If heated by ^{26}Al , smaller initial size keeps the small bodies cooler, but embryos get hotter

Initial Planetesimal Size Affects Efficiency of Planetary Formation

- Embryos stir up the residual small population, which collide
- Smaller bodies are weak, and also have more collisions
- Starting with km-sized planetesimals, about half of initial mass is ground down
- Initial size $>\sim 10$ km preserves most of available mass

Caveats

- Are outcomes different if planetesimals form over some interval, rather than instantaneously?
- Need to consider a range of initial sizes
- Fragmentation depends on more than impact energy; need to consider effects of off-center collisions